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FOREWORD

Welcome to the Abstracts Book of the *"Seabed and Sediment Acoustics: Measurements and Modelling"* conference, organised by the Underwater Acoustics Group of the Institute of Acoustics.

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The last few years have seen increasing activity in this field of underwater acoustics, and this conference aims to bring together international experts in the field. It was scheduled for September 2015 to coincide with the 10th anniversary of the successful international conference *"Boundary Influences in High Frequency, Shallow Water Acoustics"*, organised by Nicholas G. (Nick) Pace and Philippe Blondel in July 2005, also at the University of Bath. Just over 10 years before, in April 1993, the University had the privilege of hosting another Institute of Acoustics conference, *"Acoustic Classification and Mapping of the Seabed"*, organised by Nick Pace and Nick Langhorne (then at the Defence Research Agency). This followed the 1983 conference *"Acoustics and the Sea Bed"*, spearheaded by Nick Pace, which was the first large, international conference of its kind to be held at the University of Bath. All these conferences were very successful, due in no small part to the activity of their organisers and the high calibre of all contributions. 51 papers were published in 1983; 52 papers and 4 abstracts in 1993; 65 papers in 2005; 45 papers and 9 abstracts in 2015.

Omnia mutantur, nihil interit[1], as the ancients used to say. This year's conference is a witness to the many changes in the field over the last decade, and it is a pleasure to see new names and new approaches. This year's conference is also a good testimony to the legacy of excellent research, and it is a pleasure to see names from the 1983 and 1993 conferences still appearing in 2015 (albeit in a more senior position). The conference had a special session in honour of Prof. Emeritus Nick Pace and his contributions to the research community over nearly 50 years of continuous activities, with participation from former students and current collaborators. Finally, we would like to acknowledge the support of the Office of Naval Research Global (ONRG), the European Acoustics Association (EAA), the Acoustical Society of America (ASA) and the University of Bath in making this conference more accessible to everybody.

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[1] "Everything changes, nothing perishes" (Ovid, Metamorphoses).

In situ **direct measurements of sediment compressional and shear wave properties in Currituck Sound and comparison to theory**

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The geophysics of low frequency sound in extremely shallow water is not well understood, which limits practical applications. This paper reports direct in situ measurements of compressional and shear wave velocities and attenuation collected below the water-sediment interface in Currituck Sound, a shallow protected inlet on the Outer Banks of North Carolina, USA. Three measurement locations having distinctly different sediment types will be presented: (1) a near-shore site with medium-grained sand, (2) a shallow water site with fine-grained sand, and (3) an offshore site with muddy fine-grained sand. Varying amounts of biological material, including marine plants and their root systems, were present at all sites. At each site, grab samples were collected and later analyzed in the laboratory to quantify physical properties of the sediment, including grain size, density, and porosity. The acoustic data were acquired using two measurement systems, each consisting of four probes mounted on a rigid frame. The shear wave system utilized bimorph transducers to generate and receive horizontally polarized shear waves in the 300 Hz to 1 kHz band, and the compressional wave system was composed of conventional acoustic transducers containing cylindrically shaped piezoelectric elements operated in the 5 kHz to 100 kHz band. Both systems were deployed over the side of an amphibious vehicle and manually inserted into the sediment. Signals were cabled back to shipboard equipment for conditioning, digitization and storage on a computer. Wave speeds and attenuations were extracted from the measurements and compared to predictions from one or more sediment models using the input parameters obtained from the grab sample analyses. The Mallock-Wood equation, Buckingham's viscous grain-shearing theory, and the Biot-Stoll model were considered. The geoacoustic data coupled with the best-fit sediment models will provide basis for future propagation modeling in extremely shallow water. [Work supported by ERDC, ARL:UT, and ONR]

Full reference:

Lee, K.M., M.S. Ballard, A.R. McNeese, T.G. Muir, P.S. Wilson, R.D. Costley; "*In situ* direct measurements of sediment compressional and shear wave properties in Currituck Sound and comparison to theory", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 1-13, 2015

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The sedimentary and acoustic properties of deep sediments from different oceans

Thierry Garlan, Patrick Guyomard, Xavier Mathias, SHOM, France, Eléonore Köng Sébastien Zaragosi, University of Bordeaux, France

The characterisation of the seabed with acoustic systems (acoustic imagery, sub bottom profilers) and modelling of noise and acoustic propagation are both based on similar approaches. It is however not easy to use acoustical data for studies in sedimentology, or sedimentary data to acoustic models. The problems encountered come from the absence of a unique relationship between acoustic signature and seabed granularity. The sea bottom could not be defined only by the name of sediments, because it is the combination of morphology, roughness, the nature and granularity of particles, the nature and proportion of interstitial fluid, the lateral and vertical organisation of bedding. All these characteristics are defined by the regional geology, climate, depth, and the depositional processes. These elements act on granularity, density and porosity. Since the velocity and absorption of acoustic waves are only rarely measured in sediments, the acoustic behaviour of the seabed is generally modelled using transfer formulae which enable to translate the name of the sediment, its porosity or mean grain size in seabed acoustic parameters. At the present stage of our research, it appears that the differences between acoustic models and sedimentary data come essentially from the classification used to describe sediments, which is too reductionist to deal with their complexity. An improvement would be to take into account the heterogeneity of sediments, the process of deposits and the regional specificities. This approach on fine sediments from deep oceans will be extended to coarse sediments with the development of the new INSEA system (Demoulin et al). The presentation focuses on the results from core sediment analysis in different deep environments from Indian Ocean to Atlantic, and from equator to polar circle.

Full reference:

Garlan, T., E. Köng, P. Guyomard, X. Mathias, S. Zaragosi ; "The sedimentary and acoustic properties of deep sediments from different oceans", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 14-23, 2015

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Shear-wave velocity estimation using seismic interface waves generated by a shear source

Hefeng Dong, Norwegian University of Science and Technology, Norway, Kenneth Dufaut, Statoil ASA, Norway

Sediment shear-wave velocity is an important geoacoustic parameter in sound propagation and sonar performance since part of the energy loss to sediments is attributed to shear-wave conversion in the sediments. Furthermore, shear-wave velocity in the seabed provides a good indicator of sediment rigidity which is important for geoengineering and geohazard assessment. This paper presents seismic interface waves (Scholte and Love waves) generated by a shear source and inversion of the dispersion curves of the interface waves to estimate shear-wave velocity profiles in the sediments. An experiment by the shear source was conducted aiming at generating shear waves and a 4-component ocean bottom cable was used to collect data. The shear source generated a seismic signature at a low frequency below 60 Hz and was polarized in both in-line (parallel to the cable) and cross-line (perpendicular to the cable) orientation. Low-frequency Scholte- and Love-waves were generated and recorded. Dispersion curves of the Scholte- and Love-waves up to five modes were extracted by time-frequency analysis. Both vertical (SV) and horizontal (SH) polarized shear-velocity profiles were estimated by inversion of the Scholte- and Love-wave dispersion curves, respectively. Bayesian approach was used for inversion and Differential evolution (DE) global search algorithm was applied to estimate the most-probable shear-velocity models. The estimated SV- and SH-velocity profiles were compared with the core and in situ measurements at the experimental site and a good agreement was obtained.

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An improved high-spectral-resolution water-filled impedance tube measurement method.
Laurence J North, Angus I. Best, National Oceanography Centre, UK

Seafloor greenhouse gas quantification for climate change studies requires improved geophysical remote sensing including seismo-acoustic methods. Methane gas can exist as bubbles together with solid methane hydrate in Arctic seafloor sediments. To investigate bubble resonance phenomena in such sediments, a new water-filled impedance tube has been developed that will provide validation data for theoretical sediment-acoustics models. It will also provide a means of calibrating marine geophysical data by directly measuring the velocity and attenuation of sediment samples under simulated *in situ* temperatures and pressures with different gas contents. The impedance tube operates over a frequency range of 1 - 10 kHz, coincident with typical sub-bottom profiler frequency ranges, at pressures up to 60 MPa, while an external water jacket allows the temperature within the tube to be continuously varied over a range of 0 °C to 50 °C. We present a novel measurement and data inversion method developed to provide high spectral resolution velocity and attenuation measurement in the 1- 10 kHz bandwidth. Three measurement hydrophones are used to probe the complete wave-field, including all partial/multiple internal reflections, reflected from, and transmitted through 0.5 – 1m long samples. The three wave field measurements are combined to give a complex quantity that is independent of source and hydrophone transfer functions and sample position, thus eliminating major measurement system uncertainties. Frequency dependent velocity and attenuation are then extracted from the combined measurement data by numerical solution of a 1D wave propagation model. This numerical approach provides a solution for velocity and attenuation that is stable over the entire measurement frequency range, an advantage over methods employing explicit equations, that can become unstable at frequencies where sample length is an integer multiple of one-half wavelength. Finally, we demonstrate the accuracy and precision of the method by presenting example results obtained from nylon and jacketed sand samples.

Full reference:

North, L.J., A.I. Best; “An improved high-spectral resolution water filled impedance tube measurement method for marine sediment studies”, Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 24-31, 2015

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Acoustic inversion for gas bubble distributions in marine sediments: mercury results

Hakan Dogan, Paul R. White, Timothy G. Leighton, Institute of Sound and Vibration Research, University of Southampton

In recent years the need to predict and interpret acoustic propagation through marine sediments that contain free gas bubbles has become increasingly important for civil engineering, petrochemical exploration and safety, and climate studies. Although the models for the propagation of the acoustic waves through water and the determination of bubble size distributions from acoustical spectra in such media are well advanced, those for propagation through bubbly sediment are not. In this paper, we develop a method to estimate the size distribution of spherical or near-spherical gas bubbles in intertidal sediments. First, a mathematical formulation for the inverse problem of bubble acoustics in marine sediments is presented and verified with comparisons to analytical results. Second, acoustic measurements are undertaken using an experimental rig based on transmission method in order to assess the gas bubble content of sediments. The rig consists of a source transducer operating at 25-100 kHz and a hydrophone array. Measurements were made at the Mercury intertidal site of the South coast of England which is a muddy region with high organic content and low sand content. The recorded signals were processed to obtain the phase velocity and attenuation in gassy mud at this region, and these acoustic properties were then used in the inversion algorithm. Example inversion results regarding the bubble size distribution and the gas bubble void fraction in gassy sediments are presented.

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1. T. G. Leighton, Geophysical Research Letters, 34, L17607, 2007.
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4. Ph. Leclaire, F. Cohen-Tenoudji and J. Aguirre-Puente, J. Acoustical Society America, 96(6), 3753-3768, 1994.

Full reference:

Dogan, H. P.R. White, T.G. Leighton; “Acoustic inversion for gas bubble distributions in marine sediments: Mercury results”, Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 32-39, 2015

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In-situ acoustic measurements of water saturated beach sands

Xavier Demoulin**,** Maree**,** Thierry Garlan, SHOM, Laurent Guillon, French Naval Academy, Patrick Guyomard SHOM, Romain Jan, RTSYS, France

Sound speed and absorption coefficient of sandy seafloors are important parameters for many shallow water underwater acoustics applications but there is a lack of data for such sediments. In this context, a prototype has been developed: INSEA for INvestigation of SEdiment by Acoustic (see e.g., X. Demoulin et al., 1st UAC meeting, Corfou, Greece, 2013). This device is easy to use and light enough to be operated by a single diver. It gives sound speed and absorption coefficient between 80 kHz and 350 kHz. Results obtained in various area have shown that the influence of heterogeneities of sandy sediments on acoustic parameters is huge and that the scattering regime can be achieved even for small ka (wavenumber times mean grain size) product. Based on these conclusions, a new prototype has been done, with improved performances, to facilitate constitution of data bases. It operates between 50 kHz and 270 kHz and make a multi-measurement of acoustic sediment parameters in some tens of seconds. Three kind of measurements are planned to build the data base: one with beach sands, one with diver operations and one with a geotechnic module for deeper water depths. This presentation focuses on the first campaign involved with water saturated beach sands. Each campaign includes INSEA measurements and sediment samples. More than 50 beaches have been covered. Results include acoustic dispersion curve statistics and sediment analysis. They are presented and a first discussion considering heterogeneity is done.

Full reference:

Demoulin, X., T. Garlan, L. Guillon, P. Guyomard ; “In-situ acoustic measurements of water saturated beach sands”, Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 40-47, 2015

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Estimation of sediment properties using air launched sonobuoys

Subramaniam D. Rajan, Scientific Solutions Inc., USA

In air based antisubmarine warfare (ASW) operations, a field of sonobuoys that includes both acoustic sources and receivers is dropped from an aircraft. The sonobuoys work in passive/active transmission and reception modes. With the relatively recent availability of sonobuoys with GPS and the use of coherent sources under development for ASW operations, we examine the potential of using the data collected during ASW operations to extract sediment properties in the regions where the sonobuoys are deployed. We explore this possibility using data created in a simulation for which, we considered a region off the New Jersey coast that was the location of number of experiments in the past. In this general area, 25 sonobuoys are uniformly distributed. This created a network of sonobuoy receivers. A source centrally located broadcast broadband signals. The total region under consideration is divided into sub-regions with each sub-region having a different sediment model and a different water column depth. Using Fourier synthesis approach and normal mode propagation model synthetic data simulating the signals acquired by the sonobuoys are generated. We present the analysis of the simulated data and the estimation of range-dependent and range independent sediment properties using inverse methods based on mode dispersion data. We also outline some of the problems that were encountered during the analysis and the methods adopted to deal with them. The results demonstrate the potential of using data collected in routine ASW operations to obtain usable sediment geoacoustic properties that are critical to evaluate sonar performance.

Full reference:

Rajan, S.D., “Estimation of sediment properties using air launched sonobuoys”, Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 48-55, 2015

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Examining the relationship between flocculent structure and shear wave speed in muddy sediments

Megan S. Ballard, Kevin M. Lee, Preston S. Wilson, Thomas G. Muir, University of Texas, USA

Knowledge of the geoacoustic properties of high porosity fine-grained sediments is necessary to predict acoustic propagation in shallow water regions where layers of marine mud are present on the bottom. To address this need, this work study seeks to develop an understanding of the relationship between microscopic properties (e.g., flocculent structure) and macroscopic properties (e.g., shear wave speed) of fine-grained sediments, as well as to provide high-quality measurements to drive future modeling efforts. Muddy sediments are described as a colloidal suspension of thin, irregularly shaped platelets, which carry a surface charge linked to their cation exchange capacity. These suspensions result in flocculent structures, which cause mud to have high porosity and exhibit gel-like behavior. Depending on the pH and electrolytic environment, different modes of platelet-platelet interaction occur. For example, under acidic conditions, the edges and faces of the platelets will mutually attract giving rise to “card-house” flocs. At high electrolyte concentrations, both high and low pH, particles adhere to one another along their basal surfaces or faces, forming “card-pack” flocs. In this work, laboratory measurements of the shear wave speed are reported for muddy sediments formed from kaolinite platelets and water. Shear wave measurements are obtained using a pair of bimorph elements to generate and receive horizontally polarized shear waves. The sediment samples were analyzed using electron microscopy to confirm chemical composition and measure platelet dimensions. The effect of flocculent structure on the measured shear wave speed is investigated. As part of this analysis, measured wave speeds are compared predictions from an electrochemically- and mechanically-based model of the card-house structure. The results of this study are intended to lead to an increased understanding the physical mechanisms controlling acoustic propagation in fine-grained marine sediments.

Full reference:

Ballard, M.S., K.M. Lee, P.S. Wilson, T.G. Muir; “Examining the relationship between flocculent structure and shear wave speed in muddy sediments”, Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 56-62, 2015

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High-frequency scattering from a muddy sand sediment with an overlying mud layer.

Brian T. Hefner, Anatoliy Ivakin, Darrell R. Jackson, University of Washington, USA

In the spring of 2014, high-frequency acoustic scattering from the sediment was measured in St. Andrew's Bay, FL. The sediment at the experiment site consisted of a layer of mud, approximately 13 cm thick, on top of a mud/sand sediment. A probe was used to measure the conductivity of the sediment in a 2D plane covering a horizontal distance of 3 m and penetrating 25 cm into the sediment. Using bulk sediment properties determined through the analysis of diver cores, the grid of conductivity measurements was inverted to determine the variations of the density and mud content within the sand sediment. From this data, the power spectrum for the density fluctuations was estimated and, using sediment sound speed and attenuation data, the relationship between the compressibility and the density fluctuations was also determined. Both a laser line scanner and the conductivity probe were also used to measure the roughness of the mud/water and mud/sand interface. This set of environmental measurements was used to estimate the scattering from both interfaces and from the sediment volume using perturbation theory and the small-slope approximation. Acoustic scattering measurements were collected at the site using two systems. The first data set was collected using a calibrated Teledyne-RESON Seabat 7125. This system was modified to collect data from 180-420 kHz and the processing of the data for rough surface and volume scattering focused on the angles from nadir to 30 degrees off-nadir. The second system was mounted on a rail system and used two source/receiver arrays to collect scattering data from 10-500 kHz at shallow grazing angles (8-35 degrees). Both of these data sets are compared to theory and used to assess the relative importance of the different scattering mechanisms for this complex sediment.

Full reference:

Hefner, B.T., A. Ivakin, D.R. Jackson ;"High-frequency scattering from a muddy sand sediment with an overlying mud layer", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 63-70, 2015

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Estimation of scattering mechanisms and scales from waveguide reverberation measurements
Charles W. Holland, ARL-Penn State, USA

Waveguide reverberation can be controlled by scatterers in the ocean volume as well as the boundaries, i.e., sea surface and seabed. In many instances, it is the seabed that dominates the temporal and spatial character of the reverberation in shallow water regions, particularly in summer. Scattering mechanisms from the seabed can arise from sediment layer interface roughness and/or from volume heterogeneities. These heterogeneities can be described either by a fluctuation continuum or by discrete particles. Though generally difficult to discern which description applies, it is possible in principle to determine whether the scattering arises from discrete particles or a fluctuation continuum. Several shallow-water reverberation measurements are examined to estimate the scattering mechanism and its associated spatial scales. [research sponsored by the Office of Naval Research Ocean Acoustics program].

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Quantitative imaging of acoustic backscatter data from the seafloor

Kenneth G. Foote, Woods Hole Oceanographic Institution, USA, Stephen P. Robinson, Peter D. Theobald, NPL, UK

Two factors have often led to the neglect of instrument calibration and the loss of information in the imaging process: the power of the image and the convenient signal processing expedient of disregarding the physical nature of data. Seafloor imaging by sonar is a case in point. Notwithstanding ambitions and needs to remotely detect and identify bottom objects, determine seafloor properties, and quantify benthos, among other things, images of acoustic backscattering data are often used, misleadingly, as proxies for physical data. Since image processing is inherently nonlinear, the loss of physical data is immediate. Three processes that are essential to the attainment and maintenance of the physical nature of backscattering data are elaborated: sonar calibration to determine the transfer characteristics of the sonar, range compensation that addresses both geometric and radiometric factors, and beam pattern measurement or estimation.

Full reference:

Foote, K.G., S.P. Robinson, P.D. Theobald; “Quantitative imaging of acoustic backscatter from the seafloor”, Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 71-76, 2015

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Backscatter stability and influence of water column conditions: estimation by multibeam echosounder and repeated oceanographic measurements, Belgian part of the North Sea

Marc Roche, FPS Economy, V. Van Lancker, Royal Belgian Institute of Natural Sciences,
M. Baeye, Royal Belgian Institute of Natural Sciences, J. De Bisschop, Royal Belgian Institute of Natural Sciences, K. Degrendele, FPS Economy, L. De Mol, FPS Economy, S. Papili, Belgian Navy, O. Lopera Signal and Image Centre, RMA, Belgium

The European Union Marine Strategy Framework Directive requires Member States to monitor and assess the health status of their marine habitats. Belgium put forward that the spatial extent and distribution of the major habitats (sandy mud to mud, muddy sands to sands and coarse-grained sediments), as well as that of gravel beds may only fluctuate within a margin that is limited to the accuracy of the current sediment distribution maps. Due to their ability to provide simultaneous bathymetry and backscatter strength (BS), reflecting seabed nature, multibeam echosounder systems (MBES) provide a time- and cost-efficient solution to anticipate on this legal obligation. However, as there is no formal quality level scale for the BS and consequently no level of reliability of the final decibel values, evaluating the BS quantitative capabilities to monitor habitat changes remains challenging. In a monitoring context, it is absolutely necessary to investigate to what extent the mean MBES-measured BS variation -from one cruise to another- actually represents a significant change in seabed properties and not only a change in the conditions of the water column (e.g., variation in near-bed suspensions, biological effects, increased occurrence of micro bubbles in the sea surface due to wind) at the time of the measurement. In order to evaluate the relative accuracy and the repeatability of MBES BS and to examine the external sources of variance in acoustic signatures, repeated measurements combining MBES with an Acoustic Doppler current Profiler (ADP) have been performed during tidal cycles on reference areas in the Belgian part of the North Sea. Currents and BS in the water column and vertical profiling of oceanographic parameters have been investigated allowing studying the influence of water column conditions on the BS. Measurements were conducted using two MBES systems to evaluate repeatability between echosounders. Ultimate goal is to arrive at seabed mapping and analyses protocols to obtain harmonized data products from a collaborative seabed mapping community.

Full reference:

Roche, M., M. Baeye, J. De Bisschop, K. Degrendele, L. De Mol, S. Papili, O. Lopera, V. Van Lancker ; “Backscatter stability and influence of water column conditions: Estimation by multibeam echosounder and repeated oceanographic measurements, Belgian part of the North Sea”, Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 77-84, 2015

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Using the Filtering Ocean Noise Eigenvalues (FONES) algorithm to improve the seabed reflection loss estimate derived from ambient ocean data

Ben Papandreou, Dstl, UK, Peter Nielsen, NATO STO CMRE, Italy, Timothy Clarke, Dstl, UK

The traditional method for estimating seabed reflection loss using ambient sea surface generated ocean noise is well established (e.g., Harrison and Simons, JASA, 2002; 112(4): 1377-89). In this technique the relative strengths of signals measured on a vertical line array are beamformed and compared symmetrically about the horizontal plane to estimate seabed bottom loss as a function of grazing angle and frequency. The benefit of this method is to remove the need for active sources thereby offering a low-cost, passive, bottom loss surveying method. The method, however, fails when strong interfering sources are present, for example due to nearby shipping. In this paper we detail efforts to use a modified MUSIC-type algorithm. With MUSIC-type algorithms the cross-spectral density matrix (CSDM) is subjected to an eigen-decomposition and the largest eigenvalues/ eigenvectors are used to form a signal sub-space from which the signal is recomposed. The remaining eigenvalues/ eigenvectors are designated to be part of the noise sub-space and disregarded in order to improve the signal to noise ratio. Herein, the sub-spaces are interchanged: the ambient noise is the desired signal. Consequently, the largest eigenvalues and their associated eigenvectors are removed and a signal recomposed from the noise only. This reversal of MUSIC-type algorithms is designated the FONES (Filtering Ocean Noise Eigenvalues) algorithm. The FONES algorithm is applied to data collected during the Centre for Maritime Research and Experimentation's (CMRE) MAPEX2000 and REP14-MED experiments, with improvements to the derived seabed reflection loss estimate demonstrated. Experimental data measured in the absence of strong interferers is used to provide a reference data set for testing the effectiveness of the algorithm. Incorporation of the FONES algorithm with adaptive beamformers introduces severe artefacts into the estimate. Potential methods for reducing or eliminating these artefacts are discussed and applied to the data, in particular the concept of forcing the CSDM to be Toeplitz in accordance with the physics of the problem.

Full reference:

Papandreou, B., P.L. Nielsen, T. Clarke; "Using the filtering ocean noise eigenvalues (FONES) algorithm to improve the sea bed reflection loss estimate derived from ambient ocean data", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 85-92, 2015

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High-redundancy multibeam echosounder backscatter coverage over strongly contrasted relief

Jean-Marie Augustin, IFREMER, France, Geoffroy Lamarche, NIWA, New Zealand, Xavier Lurton, IFREMER, France, Arne Pallentin, NIWA, New Zealand

Backscatter imagery generated by multibeam echosounder (MBES) from flat seafloors and unique substrate is characterized by a general intensity decrease with incidence angles and a conspicuous strong response at nadir (specular). Over flat areas variations due to incidence angles are removed using an angle compensation curve and the resulting reflectivity maps are easily interpreted. Over strong relief, however, the seafloor incidence angles vary in non-trivial ways so that the resulting reflectivity maps are usually difficult to process and interpret. High-redundancy 30-kHz MBES backscatter coverage was acquired over Brother Volcano (Kermadec Arc) onboard *RV Tangaroa*, in medium-to-deep water. The survey consisted of a set of parallel lines 50-m apart. This data enables to cast a fresh eye on the angular backscatter response and to generate 1) local backscatter angular responses associated to various geographical spots and 2) reflectivity maps where the whole area is covered according to one narrow incidence angle sector. This is dramatically different from previous approaches where non overlapping swaths implied that angular responses at high and low angles could correspond to different substrates. The Brothers Volcano consists of hard volcanic rocks sometimes draped with soft sediments, therefore well suited for this type of comparison. The area is also documented with a wealth of ground-truth data which are used to validate the substrate map generated with this new data set. We used the Sonarscope® Software from IFREMER, for the processing of the backscatter and full water column dataset, and generated backscatter angular responses. The reflectivity maps generated at fixed incidence angles are rid of specular reflection and are better suited for segmentation and generation of predictive substrate maps. Comparisons with backscatter response and reflectivity maps obtained from classical coverage are presented and analysed. Our approach improved dramatically our ability to validate segmentations performed on individual swath transects.

Full reference:

Augustin, J.-M., G. Lamarche; "High redundancy multibeam echosounder backscatter coverage over strong relief", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 93-101, 2015

The institute of Acoustics encourages self-archival and the full paper can be requested from the first author: augustin@ifremer.fr

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Low-frequency sound propagation and sediment characterization in Lake Kinneret

Boris Katsnelson, R.Katsman, University of Haifa, Israel, A.Lunkov, General Physics Institute, Moscow, Russia
I.Ostrovsky, Israel Oceanography and Limnology Research

Shallow gassy aquatic sediments abundantly found in Israel and worldwide, are a source of major concern for their contribution to air pollution and global warming. Gas bubbles within sediment change effective sediment properties, including geo-acoustical parameters and thus gassy sediments characterization can be subject of an acoustical research. The experiment was carried out in Lake Kinneret possessing typical shallow water waveguide properties (depth up to 40 m, nearly constant sound speed profile) and with high gas content within top sedimentary layers suggested by preliminary studies. Acoustic source positioned at10-m depth radiated 7 sequences over two-minute series of Linear Frequency Modulated (300 Hz – 2 kHz) signals with the two-seconds duration each. Sound was recorded with a single hydrophone fixed at the depth 10 m depth at various ranges from the source: from a few tens of meters up to 6 km. Properties of signals passing from the source to receiver demonstrate the large reflection coefficient from bottom even for small reflection angles, which pinpoints the relatively small sound speed in sediment and thus suggests the presence of free gas (methane) bubbles in the upper sediment layer. The theoretical model of the sound propagation was parameterized to find characteristics of gassy sediment layer (sound speed and thickness) that would provide the best agreement between the model and our experimental measurements. We showed that the following parameters best fit the experimental results: thickness of gassy sediments of about 20-50 cm and speed of longitudinal compressional waves about 300-600 m/s. Details of the interference structure of the sound field and connection with sediment parameters are discussed.

Full reference:

Kastnelson, B., R. Katsman, A. Lunkov, I. Ostrovsky; "Low-frequency sound propagation and sediment characterization in Lake Kinneret", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 102-109, 2015

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Assessing effects of sea-bed and sea-surface scattering on acoustic propagation

Sven Ivansson, Trond Jenserud, Swedish Defence Research Agency (FOI) and Norwegian Defence Research Establishment (FFI) email: sven.ivansson@foi.se, trond.jenserud@ffi.no

The bistatic impulse response of the underwater acoustic channel is important in connection with underwater communication, for example. Measurements of the shallow-water impulse response often indicate long reverberation tails, that are not captured by traditional 2-D propagation modelling. In the present paper, 3-D ray tracing is used to model the impulse response. Rays are traced from the source to scatterer patches on the water-column interfaces and onwards to the receiver. The contribution from each patch consists of a double sum over transmit and receive rays, with propagation-loss factors coupled by a scattering kernel. Well-known scattering kernels according to Lambert's rule, for example, are separable with different factors involving the transmit and receive grazing angles, and the received energy can be computed as a product of two single sums that are updated as the ray-tracing proceeds. Physically based scattering kernels, for roughness scattering by Kirchhoff and perturbation approaches, for example, are not separable in this way, however, and a 3-D dependence including the bistatic angle appears. In the present paper, approximations are proposed to speed up computations involving such non-separable kernels. Mainly based on grazing angles and traveltime deviations, groups of rays are formed for which the scattering-kernel values differ in a similar way from certain separable approximations. For each patch and transmit-receive ray-group pair, a single-sum product is formed and corrected with regard to representative grazing angles and interface tangential ray-direction vectors. The modelling method is applied for a shallow-water data case with varying bottom topography. Efforts are made to locate the parts of the water-column interfaces with the most significant contributions. Energy-density maps for selected time intervals and time traces for energy-weighted averages of various angle parameters are used for this purpose.

Full reference:

Ivansson, S., T. Jenserud; "Assessing effects of sea-bed and sea-surface scattering on acoustic propagation", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 110-117, 2015

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Wideband wavenumber tracking in a dispersive environment
Florent Le Courtois, Julien Bonnel, Université Européenne de Bretagne, France

The acoustic propagation at low frequency in a shallow water environment is described by a small number of modes. These modes are strongly dependent on the seabed composition and their wavenumbers present great interests to infer the sediment properties. Considering a long horizontal line array (HLA), the wavenumbers can be estimated using classical spectral estimation methods. Because only a few modes are usually propagating, wavenumber spectra can also be estimated using compressed sensing. Moreover, by concatenating wavenumber spectra at several frequencies, a frequency-wavenumber representation (so called *f-k* diagram) can be displayed. This representation is adapted to characterize the waveguide dispersion. This paper introduces a particle filtering algorithm that allows tracking the wavenumbers in *f-k* diagrams. Indeed, the general waveguide physics provides a great framework to model the wavenumbers. In particular, the wavenumbers can be linked from one frequency to the next using a canonical dispersion relation that holds true in every waveguide. The proposed approach allows computation of *f-k* diagrams using short HLA. The tracking improves the wavenumber resolution. Moreover, it provides a posteriori distributions of the wavenumbers that are particularly relevant for Bayesian geoacoustic inversion algorithms. The whole methodology is successfully applied on the Shark array (32 hydrophones) for data recorded during the Shallow Water 2006 experiment.

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A spectral decomposition procedure for determining the fields at the boundaries in a PE-based reverberation model

David J Thomson, Gary H Brooke, Craig Hamm, Dale D Ellis, Maritime Way Scientific

A technique based on a single-frequency parabolic equation (PE) prediction was developed recently to determine the feasibility of computing efficient but approximate reverberation and target echo fields in various ocean waveguides.[1] The method relies on extracting the necessary time (t) information from range (r) information via the simple expedient $t = r/\bar{c}$ for some average sound speed ($\bar{c}$). Since the PE solves for the total field at each grid point, the relevant incident fields there are not readily available, especially along the sea-surface and sea-bottom interfaces. As a result, the angle-dependent boundary scattering functions can only be applied in an average sense. The incident field at the surface is particularly troublesome as the total field vanishes there for a pressure-release boundary. In this paper, we describe a spectral decomposition method for transforming the total PE field into its modal components in order to apply a given procedure[2] for determining the incident modal amplitudes at the sea-surface (and sea-bottom) for the equivalent rays of the modes. The spectral decomposition of the PE field is carried out with the aid of a correlation function that is computed during the step-by-step solution of the parabolic equation. A Fourier transform of this correlation function yields the amplitudes and horizontal wavenumbers of the individual modes directly. Subsequent processing allows for the phase of the modes to be recovered as well.

1. C. Hamm, G. H. Brooke, D. J. Thomson and M. Taillefer, Reverberation modelling using a parabolic equation model, DRDC Atlantic CR 2012–077, Defence Research and Development Canada–Atlantic, Dartmouth, NS, October, 2012.
2. J. R. Preston and D. D. Ellis, Adiabatic normal mode reverberation and clutter modeling, 11th ECUA, Proc. Inst. of Acoustics. Vol. 14(Pt. 3) 239–246. Edinburgh (2012).

Full reference:

Thomson, D.J., G.H. Brooke, C. Hamm, D.D. Ellis; "A spectral decomposition procedure for determining the fields at the boundaries in a PE-based reverberation model", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 118-126, 2015

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An approximate technique for estimating complex eigenvalues and associated eigenfunctions of the acoustic field in shallow water over an elastic half-space.

Michael Taroudakis, John Mastrokalos, University of Crete & Hellas Institute of Applied and Computational Mathematics, Greece

The presentation deals with an approximate technique for the calculation of the complex eigenvalues and associated eigenfunctions of the acoustic field in range-independent shallow water environment over a homogeneous elastic half-space, when the sound speed profile in the water varies with depth. The idea is that the eigenvalues of the acoustic field in such an environment may be derived by means of an iterative scheme, based on finite difference approximation of the partial derivatives of the pressure with respect to depth and starting values the eigenvalues of the same problem when the sound speed profile is constant. H semi-infinite elastic sea-bed is considered and the eigenvalues of the problem with constant sound speed are estimated using the “effective depth” method. The results are compared with them of the KRAKEN-C program in terms of the eigenvalues/eigenfunctions and the acoustic field itself for typical shallow water environments. Applications associated with the propagation of earthquake sound are shown to create the link between the study presented and the ultimate goal of the research work, which is associated with the earthquake characterization using its acoustic signature.

(Work supported by PEFYKA project within the KRIPIS Action of the GSRT. The project is funded by Greece and the European Regional Development Fund of the European Union under the NSRF and the O.P. Competitiveness and Entrepreneurship.)

Full reference:

Taroudakis, M.I., J.K. Mastrokalos; “An approximate technique for estimating eigenvalues and eigenfunctions of the acoustic field in shallow water over an elastic sea-bed”, Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 127-134, 2015

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Recommendations on modelling mid-low frequency acoustic interactions with the seabed
Gary Heald, Timothy Clarke, Joe Woodward, Dstl, UK

Results of a literature review conducted to update recommendations for the acoustic treatment of the seabed in underwater acoustic modelling. A particular emphasis is placed on Medium-Frequency (1 - 10 kHz) (MF)-Low-Frequency - (≤1 kHz) (LF) sounds reflecting the increased complexity of the interaction due to the LF penetration to substructure. Recommendations on the treatment of this substructure include the effects of layering. The

Viscous Grain-Shearing (λ) (VGS(λ)) equations for estimating the propagation of acoustic waves in all marine sediments are given in light of work over the last decade revealing the non-linear frequency response of sediments at lower frequencies. Consideration is also given to the modification of the forward loss from the Seabed for different scattering regimes and for propagation across range-dependent environments.

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GEOACOUSTIC INVERSION

Single receiver geoacoustic inversion using warping and matched mode processing

Julien Bonnel, ENSTA Franc, N. Ross Chapman, Stan E. Dosso, University of Victoria, Victoria (BC), Canada

Geoacoustic inversion using low-frequency impulsive sources (such as imploding glass light bulbs or combustive sound sources) can be performed using a single receiver. Common approaches are based on inverting the modal dispersion curves in the time-frequency domain, but a novel approach is presented here. It relies on a signal processing method called warping (i.e. non-linear resampling) that allows filtering (separation) of the modes recorded on a single receiver. Once the modes are filtered, standard Matched Mode Processing (MMP) can be applied. Because the single receiver context does not provide spatial diversity, MMP is performed using filtered modes at several frequency components. More precisely, the complete methodology is as follows: 1) filter the mode using warping to obtain modal time series; 2) Fourier transform each mode separately to obtain complex (frequency-domain) modal spectra; 3) restrict the mode spectra to a common bandwidth of interest where all modes are well defined; 4) within this bandwidth, perform inversion using a broadband incoherent Bartlett processor. This inversion methodology is applied to a light bulb implosion recorded during the Shallow Water 2006 Experiment. Inversion results of the experimental data are in good agreement with our knowledge of the ocean bottom in the area. In particular, results are consistent with dispersion-curve inversion performed using the same dataset.

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Time-frequency analysis and modal behavior from airgun signals in shallow water

Hefong Dong, Norwegian University of Science and Technology, Norway, M. Badiey, University of Delaware, USA
N. R. Chapman, University of Victoria, Canada

Internal waves in shallow water have pronounced impact on sound propagation and sound intensity. Sound intensity experiences focusing and defocusing fluctuation when internal waves are present or pass through the acoustic propagation track. The sound intensity fluctuation leads to variation in the observed modal structure. In this paper, broadband acoustic signals recorded in experiments at a shallow water region of the New Jersey Shelf are analyzed to study the influence of internal waves on modal structure. Modal behavior and fluctuation due to sound intensity focusing and defocusing when an internal wave front is nearly parallel to and passes through the source-receiver track are presented. The warping transform is applied to identify and isolate modes for the frequency band of 20-180 Hz. Source depth influences the excitation of higher order modes and a maximum of four modes are recovered from data generated by an airgun source at 12 m depth and 15 km distance. The filtered modes are inverse transformed back to the time domain to reconstruct the mode signals and mode spectra. Dispersion curves of the filtered mode are obtained. The analysis results under the influence of internal waves are discussed.

Full reference:

Dong, H., M. Badiey, N.R. Chapman; "Time-frequency analysis and modal behaviour from airgun signals in shallow water", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 135-140, 2015

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Bayesian image source method for geoacoustic inversion

Laurent Guillon, French Naval Academy, France, Stan E. Dosso, University of Victoria, Canada, N. Ross Chapman, University of Victoria, Canada.

The Image Source Method (ISM) is a geoacoustic inversion approach which is accurate and fast (Pinson and Guillon, JASA, 128, pp 1685-1693, 2010). The experimental set-up consists of a broadband impulsive source and a receiver array located at a distance such that only the first bottom-reflected path is recorded. The signals reflected by sub-bottom sediment layers can be modeled as being emitted by image sources which are symmetric to the real source relative to the geologic interfaces. The number and positions of these image sources is linked direclty to the sediment sound speed profile (SSP), and detecting and localizing the image sources using the recorded signals is the key step of ISM. This step reduces the number of data to invert in comparison to other geoacoustic inversion method based on travel times. Once the image sources are localized, the sediment SSP is estimated using only formulas derived from the Snell-Descartes laws of refraction.

In this presentation, a new approach of the ISM is introduced in which localization of the image sources is performed within a Bayesian formulation. Using the measured travel times between one image source and all hydrophones, we seek the source position assuming a likelihood function based on independent, Gaussian-distributed data errors. Since the direct (forward) model is known, the posterior probability density (PPD) can be sampled using the Metropolis-Hastings algorithm. Finally, the inversion algorithm is applied to each sample and thus, the PPD of the sediment SSP is obtained. Good results are obtained by Bayesian ISM on synthetic data and real data obtained in tank or at-sea experiments. The results are compared to other geoacoustic inversion methods based on travel-time data. The inversion algorithm is also applied to synthetic data obtained with a deformed array.

Full reference:

Guillon, L., S.E. Dosso, N.R. Chapman, "Bayesian image source method for geoacoustic inversion", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 141-148, 2015

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Can high-resolution marine geophysical data be inverted for soil properties?

Mark E Vardy, National Oceanography Centre, UK, Maarten Vanneste, Norwegian Geotechnical Institute, Norway, Timothy J. Henstock, National Oceanography Centre, UK , Eugene Morgan, Penn State University, USA
Luke J.W. Pinson, SAND Geophysics, UK

For hydrocarbon prospection, the inversion of marine geophysical data for remote reservoir characterisation has developed enormously over the past 20+ years. While some techniques (e.g., waveform inversion) are prohibitively computationally expensive to permit widespread application across all targets, other less expensive variants (e.g., impedance and amplitude-versus-angle inversion) have become a standard component of most interpretation workflows. In contrast, there has been very little progress toward the remote classification of near-surface sediments through the inversion of high-resolution geophysical data, with both academia and industry relying on extensive coring and stratigraphic correlation. Here we present the successful application of post-stack acoustic impedance inversion to three marine, near-surface geophysical case studies covering lacustrine, fjordic, and near-shore environments. Chirp, Boomer and Sparker data are inverted for acoustic quality factor (Q) and acoustic impedance (Z). These can be related to P-wave velocity, density, porosity and mean grain size using global empirical relationships, while site-specific parameters (such as G_{max}, undrained shear strength, and cone resistance) can be geostatistically derived using core and CPTU data for calibration. Furthermore, through the application of soil mechanical models (e.g., White's model), these elastic properties can be used to calculate engineering properties like gas saturation, pore pressure, and consolidation. In all three case studies, the inversion results demonstrate excellent correlation with direct sampling. We can identify metre-scale stratigraphic changes, as well as subtle decimetre-scale structure, such as the grading within a glaciogenic sequence and a 40 cm thick landslide glide plane. The remote derivation of such high-fidelity soil properties has significant applications, both within academia and the offshore services/exploration industry.

Full reference:

Vardy, M.E. M. Vanneste, T.J. Henstock, E. Morgan, LJ.W. Pinson; "Can high-resolution marine geophysical data be inverted for soil properties?", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 149-156, 2015

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Impact of Ambient Noise and Ship Tonals on the Inversion of Seafloor Reflectivity from Range-Frequency Striations in Shallow Oceans

Adrian D. Jones, David W. Bartel, Paul A. Clarke, Defence Science and Technology Organisation, Australia

The broadband component of the acoustic data received in a shallow ocean from a passing ship-of-opportunity provides a convenient data set from which a pattern of range-frequency striations may be generated and seafloor reflectivity may be inverted. As previously presented by the authors (Jones, Clarke and Bartel, OCEANS'13 San Diego) the inversion technique is based on a relationship between a measure of the frequency spacing of the striations, the ocean depth, and an assumed function of reflection loss in dB versus grazing angle at the seafloor. For practical use, the technique is limited by the contamination of the striation data both by the prevailing level of ambient ocean noise, and from tonals radiated by either the ship-of-opportunity, or by any other source. This paper briefly reviews the inversion technique, and describes an analysis by which the limitations from interfering broadband and tonal data may be quantified. Demonstration is provided using synthetic data.

Full reference:

Jones, A.D., D.W. Bartel, P.A. Clarke; "Impact of ambient noise and ship tonals on the inversion of seafloor reflectivity from range-frequency striations in shallow oceans", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 157-164, 2015

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Scientific overview of the contributions of Nick Pace to underwater acoustics: research and applications
Philippe Blondel, University of Bath, UK

Prof. Nicholas G. Pace has made high-profile contributions to a number of different fields of underwater acoustics, and most of us have used his research at some point in our careers. Nick's research career is spanning close to 50 years, with a first publication in Nature in 1967 and the latest one just a few weeks ago, in another prestigious journal. This first presentation in the Special Session devoted to Nick will highlight his research career, first at the University of Durham (UK) and mostly at the University of Bath where he moved in 1970. Nick was detached for 10 years at the NATO research centre in La Spezia (Italy), then known as SACLANTCEN. He came back to Bath in 2005, where he is now Professor Emeritus. The breadth of Nick's contributions to underwater acoustics will be explored through his many research papers, many of which have become key references in the field and are still known (and cited) several decades later. These results bridge the gap between theoretical research (e.g. statistics of seabed scattering) and its applications (e.g. mine detection, seabed classification, seismic imaging), sometimes in domains far beyond seabed and sediment acoustics. With many dozens of high-profile publications, international patents, widely-read technical reports and always appreciated conference publications, Nick's impact has been strongly felt over the years, and will continue to be felt for a long time.

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A tribute to Professor Nick Pace: acoustic backscatter, imaging and classification of the sea floor

Gary Heald, Dstl, UK

Professor Nicholas G Pace was awarded his PhD from Durham University in 1970 for his research entitled 'Ultrasonic propagation and binding in solids'. Shortly after this he started his long career in the Department of Physics at the University of Bath. He has conducted research and development in many areas of acoustics and sonar applications. He is particularly well known for his research on the interaction of high frequency acoustics with the seabed. This has been applied in mine countermeasure applications and for the measurement, classification and mapping of seabed sediments. His research encompasses a wide range of topics including propagation of sound in shallow water and fluctuations in the ocean. He has worked on many types of sonar, including echo sounders, sidescan sonar, multibeam echo sounders and parametric sonars. In more recent years his research has included developments in synthetic aperture sonar, which offers high-resolution sidescan images from the seabed, provided the variability can be compensated, and bistatic sonar. He is widely published in many international journals and has many conference papers in the open literature. His work is frequently cited in others papers and he holds a number of patents, particularly from his collaboration with his former student, Jacques Guigne. In1983 he organised and chaired the first in the series of Institute of Acoustics conferences on seabed and sediment acoustics and many of the papers from that conference are frequently cited. This has been followed by the seabed conferences, held at Bath University in 1993, 2006 and now this conference in 2015. He is a Fellow of both the Institute of Acoustics and Acoustical Society of America. He was an active member of the IOA underwater acoustics group committee for many years.

During his years at Bath University he was frequently called upon to conduct research for the Admiralty Scientific branches of the MoD (AUWE, ARE, DRA, DERA) where he was well known and highly respected. This research included many studies on various aspects of sediment acoustics, over a wide range of frequencies, but also included projects investigating shallow water acoustic propagation and bubble acoustics. In the latter part of his career he was given leave of absence from the University to take up a position Saclantcen (now cmre) in La Spezia, Italy. During his time at the NATO centre he led teams investigating environmental acoustics (modelling, experimentation and statistical analysis), mine countermeasure sonar, force protection and seafloor mapping. He and his team also developed techniques for accurate ground truthing, including stereo photography and CT scanning of core samples. He also hosted many international scientists at the centre, as both visitors, as part of joint collaboration programmes and at the international conferences held in Lerici. Professor Pace is now an Emeritus Professor at the University of Bath. The international underwater acoustics community, his colleagues and former students (many of whom still work the field of acoustics) are indebted to him for his excellent contribution, guidance and leadership.

Full reference:

Heald, G.J., "A tribute to Professor Nick Pace: Acoustic backscatter, imaging and classification of the sea floor", Proc. Institute of Acoustics, vol. 37, pt. 1, p. 165, 2015

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Mapping of sub-seabed anomalies in seismically heterogeneous marine soils

Jacques Yves Guigné, University of Bath & Acoustic Zoom Inc, Canada, Adam Gogacz, Acoustic Zoom Inc, Canada

High-resolution acoustic surveys for marine applications are front line exploration tools for major offshore developments where the seabed acoustic data is characterized by spurious reflectors emerging discontinuously. With increasing oil and gas as well as renewable energy sector activities reaching into the North Sea, Baltic Sea, Irish Sea, and the Grand Banks the presence and character of glacial tills poses many uncertainties in describing the presence and nature of geohazards. In particular such regions bear a substantial number of buried boulders and over-consolidated sediments. For instance, the presence of boulders, defined as rock fragments with diameter larger than 0.3 meters, poses an engineering risk to the construction of marine structures (e.g. offshore wind-turbines or oil and gas platforms) due to either total rejection or deflection of driven foundational piles. Deciphering the signals scattered from boulders and/or till deposits and from discontinuous hardpan structures, along with dealing with the presence of gas in the sediment, remain difficult problems to remotely sense. Physical boreholes are also made problematic by buried boulders and are often of limited value because their spatial and temporal scales are discordant in resolutions with the targets to image. Ambiguities and inconsistencies in datasets collected have remained problematic to offshore engineering operations. In recent times a move to multiple echo energy and signal-shaped sonar systems—operated in tandem with broadened bandwidths, shorter pulse lengths, customized pulse shapes and beam-widths—have provided datasets that capture more complete acoustic responses of sub-bottom properties. These datasets have proven to be more useful in classification-based surficial geology distribution maps, although performances are still subject to a range of degradation effects and calibration is not always easy and often remains ambiguous. There remains a technology gap for dealing with marine seabed site investigations. Geophysical approaches do not hold the fine scales, density, or multiplicity of data to capture the distribution of inhomogeneous sediment properties with exactitude. This is especially true when the presence of boulders, gas in sediments, lenses and/or pockets of soft or hard sediments characterize a seabed. In addition, the limited sampling scales of geotechnical probes and corers hold little spatial distribution knowledge. This presentation illustrates the development of a stationary probe that produces high-energy, deep-penetrating acoustic signals within a sedimentary volume. It illustrates a step towards providing meaningful geotechnical data from offshore environments. The concept behind the instrument and methodology, referred to as an "Acoustic Sub-seabed Interrogator" (ASI) by Guigné (1986), is a radical departure from that of conventional geophysical profilers. To address these shortcomings, Guigné (1986 to present) experimentally developed an "acoustic core" answer product, which formed the basis of his PhD research under Prof. Nicholas Pace. It was through the University of Bath that this new geophysical/geotechnical concept was first introduced. The ASI is purpose designed to acquire a scattering (acoustic) response of the sub-seafloor on a dense grid. Processing of the data is based on a (acoustic) back-projection operator obtained from the first term of the asymptotic expansion of Green's function (ray theory) and the Born approximation for the scattered field. This processing method akin to and otherwise known as beamforming requires that a background compressional-wave (P-wave) speed of the soil be known a priori. The discussed method shows how to determine the background P-wave model based on user-driven diffraction-focusing technique. This technique is illustrated on synthetics as well as real data (Grand Banks) with a discussion of failure to detect boulders if the background P-wave model is not sufficiently accurate.

Full reference:

Guigné, J.Y., A. Gogacz; "Mapping of sub-seabed anomalies in seismically heterogeneous marine soils", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 166-174, 2015

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Exploiting the coherence of seabed scattering for repeat-pass SAS micro-navigation

Alan J. Hunter, University of Bath, UK, Samantha Dugelay, NATO Science and Technology Organization, Italy

The redundant phase centre (RPC) micro-navigation algorithm is crucial for generating focused synthetic aperture sonar (SAS) images of the seabed. The algorithm exploits the spatial coherence of the scattered acoustic field to make precision sub-wavelength measurements of the relative platform geometry between subsequent pings. RPC micro-navigation was recently generalised to further exploit the temporal coherence of the scattered field in order to estimate the relative geometry between repeated passes. In this paper, we investigate the constraints imposed on repeat-pass RPC micro-navigation by the limited spatial coherence of the sediment back-scattering. We use theory as well as experimental SAS data collected by the CMRE MUSCLE autonomous underwater vehicle. The results provide an indication of the tolerable bounds on the geometrical differences of repeated passes and rough guidelines for operational use of the algorithm.

Full reference:

Hunter, A.J., S. Dugelay; “Exploiting the coherence of seabed scattering for repeat-pass SAS micro-navigation”, Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 175-182, 2015

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Estimation of seafloor height fields with side-looking sonar systems

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The estimation of relative or absolute seafloor height fields from side-looking imaging sonar systems has been an active area of research for several decades. Topographic measurements (or the heights and shapes of objects on the seafloor) made with synthetic aperture sonar (SAS) systems generally use interferometry between complex images obtained from two closely-space arrays. Other possibilities for estimating small scale topography exist, including clinometry which uses intensity information in single images (e.g., shape-from-shading or shape-from-shadow techniques) and sonargrammetry, a technique based on optical photogrammetry which utilizes the parallax of pairs of images of the same area acquired with two different viewing angles. This paper reviews the different methods used to extract absolute or relative seafloor topography and discusses the respective advantages, difficulties and constraints for each technique. We further assess the possibility of using combinations of these techniques as complementary sources of data.

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Through-the-sonar seafloor characterization using lacunarity

David P. Williams, NATO STO CMRE

A new approach for characterizing seafloor in side-looking sonar imagery is proposed. The approach is based on lacunarity, which measures pixel-intensity variation, of through-the-sensor data. This simple yet powerful scalar quantity has been used in the past for anomaly detection, but we demonstrate that it can also be used to identify more subtle differences not readily apparent to the naked eye in synthetic aperture sonar (SAS) imagery. In particular, we provide evidence that the lacunarity can detect regions of poor image quality, effectively distinguishing them from flat benign seabed. Additionally, we show results that suggest lacunarity can more finely classify benign seabed in terms of sediment composition (e.g., discriminating mud from sand). It is also shown how lacunarity can readily distinguish different seafloor conditions, such as posidonia, rocks, and sand ripples. If desired, a hard segmentation of an image into discrete seabed classes based on the lacunarity values can also be effected. All this environmental information can be exploited for mine countermeasures operations in several ways, including target-detection performance prediction, environmentally adaptive feature extraction and classification, and *in situ* mission-time estimation. We also show how lacunarity can be computed very quickly using integral-image representations, thereby making real-time seafloor assessments onboard an autonomous underwater vehicle (AUV) feasible. The promise of the approach is demonstrated on high-resolution SAS imagery collected by the MUSCLE AUV at nine different geographical sites with diverse seafloor conditions.

Full reference:

Williams, D.P., “Through-the-sonar seafloor characterization using lacunarity”, Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 183-190, 2015

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Where the sonar equation fears to tread

Derek R. Olson, Daniel C. Brown, Charles W. Holland, Cale F. Brownstead, The Pennsylvania State University, USA

The seafloor scattering cross section is typically extracted from acoustic reverberation data by inverting some form of the sonar equation. In these cases, the incident field driving the scattering is assumed to behave locally like a plane wave, which is typically correct for interface scattering at low grazing angles. However certain situations, such as near-specular interface scattering, and volume scattering in a layered or refracting seafloor, can cause this assumption to be invalid. In these cases, measured acoustic intensity is proportional to a sum or integral of the scattering cross section over a variety of angles. As an alternative to the sonar equation, an empirical or physical model of the scattering cross section can be used to compute model intensity time series, which are then fit to measurements. This optimization procedure results in model parameters that can produce parametric estimates of the scattering cross section over the frequency and angular domain covered by the experimental setup. This technique is used to estimate the scattering cross section in situations where the sonar equation is invalid using data measured with a synthetic aperture sonar with a 100 kHz center frequency and a normal-incidence real aperture sonar with a center frequency of 18 kHz. Modeling of the environment is discussed as well as, complications introduced by the optimization problem, including confidence regions, degenerate solutions, and computational cost. Support for this work was provided by the Office of Naval Research.

Full reference:

Olson, D.R., D.C. Brown, C.W. Holland, C.F. Brownstead, “Where the sonar equation fears to tread”, Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 191-198, 2015

The institute of Acoustics encourages self-archival and the full paper can be requested from the first author: dro131@psu.edu

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Evaluation of multipath effects on SAS imagery

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In the presence of multipath spreading, which is common in shallow water, sonar imagery is usually disturbed by the contribution of none-direct paths. This holds for conventional side scan sonars as well as for synthetic aperture sonars (SAS). Because SAS imagery is based on data driven motion estimation the limitations resulting from multipath can be even more severe. In this paper the influence of multipath on SAS imagery is evaluated. Therefore, we presuppose that the imagery is based on correct motion estimation. This is usually the case if multipath spreading is limited and, thus, only visible for strong scatterers. In this case the contribution of multipath to the image is less dominant for SAS processing because of the extended length of the (synthetic) aperture and the different positions of transmit. For our analysis we use data from the SeaOtter MKII AUV system of WTD 71 equipped with a LF and MF SAS system, which illuminate the same patch of seafloor during the same track. We compare the amplitudes of multipath propagation for single ping data and for SAS images. Additionally, the different impact of the dissimilar frequencies will be examined. Results of simulations are presented as well which show the expected ratios for the two SAS systems for single ping data and for SAS images taking into account the physical parameters of the antenna and source. These results will be compared with the findings based on the SAS measurements.

Keywords: Synthetic aperture sonar, Multipath

Full reference:

Ehrlich, J., H. Schmaljohann, W. Jans, "Evaluation of multipath effects on SAS imagery", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 199-206, 2015

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Interference rejection for sonars via low complexity adaptive beamforming

Tor Inge Birkenes Lønmo, Kongsberg Maritime, Norway**,** Andreas Austeng, Roy Edgar Hansen, University of Oslo

The delay-and-sum (DAS) beamformer is commonly used in active sonar imaging. However, it suffers from high sidelobes, which make it susceptible to masking of weak signals when there are strong, interfering, signals present. This may cause serious problems, as low quality or loss of data and range reduction. Conventional aperture shading is used to mitigate this, with a trade-off against resolution. Adaptive methods promise to provide increased sidelobe suppression without loss in resolution. This is done by adjusting the beam pattern to have low gain in the directions with interference and allowing large sidelobes in directions without signal. In this work, we investigate the interference rejection capabilities of the Low Complexity Adaptive (LCA) beamformer. LCA is a computationally cheap version of the Minimum Variance Distortionless Response (MVDR) beamformer. It uses a discrete search space and bases its decision on a single sample. The discrete search space also make LCA resistant to signal suppression, which is a serious issue for MVDR in active applications. We put LCA to the test by applying it to data collected by a high-resolution echosounder over the wreck of an oil tanker. The wreck has sharp edges and big differences in backscatter level, which is common challenges for the DAS beamformer. We investigate how LCA performs compared to the unweighted and a weighted DAS beamformer.

Full reference:

Lønmo, T.I.B., A. Austeng, R.E. Hansen, "Interference rejection for sonars via low complexity adaptive beamforming", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 207-214, 2015

The institute of Acoustics encourages self-archival and the full paper can be requested from the first author: tor.inge.birkenes.lonmo@km.kongsberg.com

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Modelling seafloor bioturbation

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The littoral seafloor is a dynamic environment; hydrodynamic and biologic forces continuously modify the seabed relief. Sandy environments are often the most active, with storm and tidal forces organizing sediment into orbital ripples while bottom-feeding and bottom-dwelling organisms rework the seafloor (i.e. bioturbation), destroying this structure and returning it to random equilibrium. Understanding and predicting the temporal evolution of the seafloor is vital for a variety of oceanographic (e.g. hydrodynamic flow in the presence of sand ripples) and acoustic (e.g. synthetic aperture sonar-based coherent change detection) techniques. In this paper, we present an amalgamation of model and numerical simulation to represent and predict the impact of bioturbation on seabed relief. A previously presented model representative of a fish feeding pit is further developed with consideration of horizontal diffusion, and extended to provide the ability to predict seafloor roughness equilibrium power spectra. This formalization of equilibrium power spectra is compared to numerical simulations for a variety of forcing function sizes and probability density functions.

Full reference:

Johnson, S.F., D.R. Jackson, "Modelling seafloor bioturbation", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 215-224, 2015

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Simulation of measured seafloor roughness spectrum time series using a coupled ripple bioturbation model

Allison Penko, Shawn Johnson, Joe Calantoni, Naval Research Laboratory, USA

Ripple formation by waves and ripple degradation from biological activity are opposing forces occurring continuously on the seafloor. Existing ripple models are often based on the seafloor being in equilibrium with the wave conditions and neglect any change due to bioturbation. Additionally, typical equilibrium ripple models only provide geometric dimensions (e.g., height and wavelength), not a roughness spectrum necessary for acoustic applications. A spectral seafloor model is presented that predicts the spatial and temporal evolution of seafloor roughness accounting for both the evolution and degradation of ripples due to waves and biology. The time dependent spectral model is based on the assumption that each wave number component of seafloor spectra evolves independently. The spectral seafloor model is coupled to a bioturbation model that simulates the evolution of the seafloor spectra due to biological activity. The bioturbation simulation is a procedural generation technique whereby a biologically-inspired basis texture is applied to seafloor relief at a specified rate. The coupled model system predicts a time series of the roughness spectrum given the sediment type and a time series of wave conditions. Predictions made by the coupled model are compared to high frequency (2.25 MHz) sector scanning sonar data collected during the Target and Reverberation Experiment (TREX13). The sector scanning sonar imaged a small area of the seafloor (~15 square meters) every 12 minutes for 34 days (20 April – 23 May 2013) around a quadpod deployed in 7.5 m depth offshore of Panama City, FL USA. The image sequence provided high-resolution observations of ripple growth, decay, and reorientation under a wide range of forcing conditions.

Full reference:

Penko, A., S. Johnson, J. Calantoni, "Simulation of measured seafloor roughness spectrum time series using a coupled ripple-bioturbation model", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 225-233, 2015

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Sensitivity of macroinvertebrates to substrate borne vibration

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To assess and understand the impact of anthropogenic vibration upon marine organisms we first need data on the detection capabilities of these species. Many marine developments involve techniques directly contacting the seabed, such as pile driving, and it is likely that benthic animals are being exposed to strong seabed vibrations during construction. There are few data available on their sensitivity to such stimuli. Vibration is likely to be used for detection of biotic and abiotic environmental cues, and exposure may affect key behaviours such as the ability to escape predators and to forage successfully, however the area is relatively unstudied in recent years. Here the sensitivity of unconditioned macroinvertebrates (bivalves and crustaceans) to substrate-borne vibration was determined during vibration exposures, allowing the production of sensory threshold curves and an examination of response variation under controlled conditions. Thresholds and behavioural responses were related to measurements of seabed vibration taken within the vicinity of anthropogenic operations, allowing sensitivities to be related to exposure levels that may be encountered. The data are a step towards understanding the sensitivity of benthic invertebrates to substrate-borne vibration, and indicate that the effects of seabed vibration should not be overlooked when investigating the effects of anthropogenic pollution on marine species.

Full reference:

Roberts, L., S. Cheesman, M. Elliott, T. Breithaupt; "Sensitivity of macroinvertebrates to substrate borne vibration", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 234-241, 2015

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Seafloor backscatter acquisition and processing: best practice and recommendations by the GEOHAB backscatter working group

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Craig Brown, Nova Scotia Community College, Canada, Erin Heffron, QPS Inc, USA, Vanessa Lucieer, University of Tasmania, Australia, GlenRice, NOAA, USA, Alexandre Schimel, Deakin University, Australia, Tom Weber, University of New Hampshire, USA

The Marine Geological and Biological Habitat Mapping (GeoHab) group gathers a community of geoscientists and biologists around the topic of marine habitat mapping, with a strong technological component. During the GeoHab 2013 annual meeting, a workshop dedicated to multibeam seafloor backscatter concluded the need for better coherence and common agreement on acquisition, processing and interpretation of data. Subsequently, the GeoHab Backscatter Working Group (BSWG - more than 120 people to date) was created; its purpose was to document and synthetize the state-of-the-art in sensors and techniques available today and to propose methods for best practice in the acquisition and processing of multibeam sonar backscatter data. The resulting document "Backscatter measurements by seafloor mapping sonars: Guidelines and Recommendations", includes seven chapters written by several specialists coordinated by the co-authors of this paper:

1. an introduction to backscatter measurements by seafloor-mapping sonar;
2. a background on the principles of sonar and physical backscatter, with some fundamental definitions;
3. a discussion on user's needs based on a short survey from a wide spectrum of community end-users;
4. a review on backscatter measurements by actual bathymetric echosounders;
5. an analysis of best practices in backscatter data acquisition ;
6. a review of backscatter processing principles with details on present software implementation;
7. a synthesis and a number of key recommendations.

Designed to reach a wide audience of scientists, engineers, operators and stakeholders all using sonar backscatter for seafloor-mapping applications, the BSWG report proposes fundamentals of the topic, a state-of-the art of techniques, and a number of recommendations for future systems and processing. The paper reviews the BSWG mandate, structure and work program; it details the various chapter contents; and emphasizes the conclusions of the report and in particular its recommendations to operators, endusers, sonar-system manufacturers, and developers of processing software.

Full reference:

Lurton, X., G. Lamarche, C. Brown, E. Heffron, V. Lucieer, G. Rice, A. Schimel, T. Weber, "Seafloor backscatter acquisition and processing: Best practice & recommendations by the GeoHab Backscatter Working Group", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 242-249, 2015

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Acoustic textures and multibeam mapping of shallow marine habitats – examples from Eastern Malta

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Multibeam sonars are now used in increasingly shallower waters, bringing very high resolution imagery and bathymetry from often very varied seabeds. These developments have been associated with technological challenges, such as the adaptation of systems designs for deeper waters to more restricted ranges, often with multiple reflections. They have also brought a step change in acoustic mapping, with at least an order of magnitude in resolutions now attainable, coupled with a higher susceptibility to small-scale variations. This paper will investigate how these changes affect seafloor classification, focusing on the role of acoustic textures of shallow habitats. Maps of marine habitats have several purposes, from ecological (ecosystem health monitoring, marine-protected areas) to socio-economic (resource accessibility and sustainability, changes brought by pollution or offshore activities). Classifications must therefore successfully address the relevant types of information. This will be presented using a high-resolution multibeam dataset acquired on the eastern coast of the island of Malta in May 2012, in water depths of 1.5-400 m. The 70-100 kHz Kongsberg EM710 multibeam echosounder was deployed over diverse terrains including horst and graben alternations, seagrass cover in some areas, gravel and different sediment types. After full processing, the dataset provides multibeam backscatter at 1-m resolution and bathymetry at 2-m resolution, supplemented with photographic ground truth and samples at appropriate locations. The results of acoustic texture analyses will be presented in the context of data acquisition choices (e.g. pulse lengths, survey speeds), terrain morphology (role of slopes and large-scale types) and multi-scale terrain variability (bathymetry and backscatter).

Full reference:

Blondel, Ph., M. Prampolini, F. Foglini, "Acoustic texture and multibeam mapping of shallow marine habitats – Examples from Eastern Malta", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 250-257, 2015

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Sub-bottom imaging with variable beam widths

Bjornar Langli, Kongsberg Maritime, Norway

Echoes received by sub-bottom profilers (SBPs) are a mixture of specular reflections and backscatter. The area contributing to a specular reflection is typically much smaller than the footprint of the sonar. Often backscatter levels in sediments are low and the resulting echoes are dominated by the specular reflections. Under such conditions wide-beam SBPs may provide very good imaging. High levels of backscatter can obscure the specular reflections. Reducing the footprint of the SBP will improve the specular reflection to backscatter ratio under one condition: The direction of the specular return must be within the SBPs main lobe. This points towards the challenge of narrow-beam SBPs: the narrower the beam the more susceptible the system will be to sediment slopes. Most narrow-beam SBPs will have the capability to tilt the beam electronically to maintain normal incidence to sediment interfaces. However, this is in practice awkward as the slope angle will change both with position and range. The SBP 120/300 systems from Kongsberg Maritime are multibeam SBPs with beam widths down to 3 degrees. Recently, in response to the challenge of narrow beams and sloping sediments, a new operating mode has been added with cyclic variation of the transmit beam width allowing sub-bottom profiling with different beam widths in a single pass. This mode is well suited to demonstrate the impact reducing the beam width when the level of backscatter is high. The relevant capabilities of the system will be described and data examples will be given. These systems offer a swath of narrow receiver beams per ping providing robustness with respect to acrosstrack sediment slopes. This may also be useful for the study of backscatter since the narrow beams enable separating backscatter from the coherent reflections. Experimental results will be shown.

Full reference:

Langli, B., "Sub-bottom imaging with variable beam widths", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 258-264, 2015

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Sensing the seabed vibrations - especially the interface waves

Dick Hazelwood, R+V Hazelwood Associations, UK

In addition to the much studied interactions with sound from the overlying water, there are waves which are confined to the seabed, with energy which propagates with little leakage from vibratory sources. Natural modes of some realistic models occur at low frequencies with very low wave speeds ~ 100m/s. These waveforms do not couple with pressure waves in the bulk media, and can be considered quite separately. Their effects can be sensed within both solid and fluid media adjacent to the interface, but show an evanescent decay as the sensors are moved away. Their water particle motions are circular, quite different from the linear motions of plane waves created by sounds in the bulk water. Whilst they can be detected by hydrophones, measuring motion with inertial sensors mounted close to the seabed can be more effective. It is widely understood that many creatures which occupy this habitat sense such water particle motion, and recent results have shown more details of their sensitivities. A detailed description of the signals from geophones will be presented, aiming to assist the analysis of biological research work. Geophones have minimal pressure sensitivity, and provide a low noise voltage response to the velocity of motion which is flat over many octave frequency bands. Analysis of their structure and that of accelerometers will be compared to the otolith organs in fish. Crustaceans are relatively immobile and thus easier to study. Their inertial sensitivities are being measured in small tanks, to be considered as rigid bodies at the low frequencies where both geophones and biological inertial sensors are most sensitive. Provided these closed tanks are kept full, there will be little acoustic pressure variations within. Any observed response will then assigned to inertial effects.

Full reference:

Hazelwood, R.A., "Sensing the seabed vibrations – and simulating the seismic interface waves", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 265-272, 2015

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The effect of bathymetric measurement uncertainties on multi-beam echo-sounder sediment classification

Mirjam Snellen, Delft University of Technology, & Deltares The Netherlands, Kerstin Siemes, Delft University of Technology, The Netherlands, Jeroen Janmaat, Delft University of Technology, The Netherlands, Dick G. Simons, Delft University of Technology, The Netherlands

In the framework of the Dutch Natura2000 program, multibeam echosounder (MBES) measurements were taken in the Cleaver Bank area (North Sea, The Netherlands) in 2013. Natura2000 aims at closely monitoring marine environments and coordinating all activities within selected areas such that their flora and fauna are not negatively affected. The Cleaver Bank area is one out of 160 areas monitored in the Natura 2000 program. The backscatter strengths as measured by the 300-kHz MBES have been used for classifying the surface sediments in the area. A comparison with the classification results from an MBES survey as carried out in 2004 shows a very good agreement, indicating a temporally stable sediment distribution in the area. Also a very good agreement was found between the acoustic classification results and the sediment characterization as obtained from grab samples. In addition to the backscatter measurements, also the bathymetric measurements contain information regarding the sediment properties. A parameter often used are the so-called depth residuals. This parameter is obtained by locally fitting planes through the MBES depth measurements and considering the least-squares residuals. In theory, this is a measure for the roughness of the sea-bottom. In practice, however, the variations in bathymetry are not caused by the actual bottom roughness alone, but also by the intrinsic uncertainty in the bathymetric measurements, which results from uncertainties in amongst others the travel time, water sound speed, and ship attitude. To predict these intrinsic uncertainties, we present the model AMUST (A priori Multi-beam Uncertainty Simulation Tool). It will be used for assessing the uncertainty in the bathymetric measurements as expected for the Cleaver Bank measurements. This knowledge is prerequisite when the aim is to derive the sediment roughness, in addition to the backscatter strength, from MBES measurements.

Full reference:

Snellen, M., K. Siemes, J. Janmaat, D.G. Simons, "The effect of bathymetric measurement uncertainties on multibeam echosounder sediment classification", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 273-280, 2015

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Ambient noise measurements from hydrophones buried in a mixed-gravel beach

David R. Barclay, Alex E. Hax, Dalhousie University, Len Zedel, Memorial University of Newfoundland
Ying-Tsong Lin, Woods Hole Oceanographic Institution

Ambient noise recordings were made on pairs of hydrophones buried in the seabed of a mixed gravel and coarse sand beach near Advocate Harbour, on the Bay of Fundy, Canada, over a period of three weeks. The beach has a tidal range of 10 meters and is sloped 10:1. The pairs of hydrophones were arranged at mid-tide in vertical, horizontal along-shore and horizontal across-shore orientations to provide pressure time series, power spectral density, and vertical and horizontal coherence measurements of the noise field in the seabed. A buried acoustic source was used to directly measure the compressional wave speed in the seabed on the across-shore array. Noise generated by inter-granular collisions was measured when the swash zone was directly above the buried hydrophones. However, during the remainder of the tidal cycle, poroelastic interface waves generated by plunging surf on the beach face dominated the ambient noise field. The Green's function between the across-shore pair of hydrophones was estimated by cross-correlating the noise, and provides an estimate of the propagation speed of the compressional component of the interface wave in the unconsolidated sediment. A nearby suite of instruments measured the ocean wave properties, bed dynamics and weather during the experiment.

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3-D SHALLOW WATER ACOUSTICS

Ying-Tsong Lin, Woods Hole Oceanographic Institution, USA

Study of three-dimensional (3-D) sound propagation effects in areas of continental shelves and shelfbreak is reviewed. A variety of environmental factors in these areas, including topographic variability, water column fluctuations and boundary roughness, can cause lateral heterogeneity in medium properties. Thus, horizontal reflection or refraction of sound can occur, and it produces strong 3-D acoustic effects. Theoretical, numerical and experimental approaches have been taken, and some of the research results are presented in this paper. The main objective of this research is to study the underlying physics of the 3-D sound propagation effects produced jointly by physical oceanographic processes and geological features. The contributions of the work include assessment of the environment-induced acoustic impacts and improvement of the capability of sonar systems in complex shallow water areas. [Work supported by the Office of Naval Research, USA]

Full reference:

Lin, Y.-T., "3D shallow water acoustics", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 281-288, 2015

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3D modeling of spherical wave reflection on layered media with rough interfaces

Samuel Pinson, Julio Cordioli, Universidade Federal de Santa Catarina, Brazil

In the context of sediment sound-speed profile characterization, the influence of interface roughness remains unstudied. One of the main reasons is the difficulty to properly model reflected waves over a layered media with rough interfaces. Although roughness scattering has an abundant literature, 3D modeling of spherical wave reflection on rough interfaces is generally limited to a single interface (using Kirchhoff-Helmholtz integral) or to a small volume domain (using Finite Element Method or Finite Difference Method). In this communication, we present a method to model such a reflection with a reasonable computation cost. The method uses three approximations: the tangent-plane approximation, The Born approximation (multiple reflection between interfaces are neglected) and flat-interface approximation for the transmitted waves. The validation of the code is made in 3D by a comparison with the Sommerfeld integral numerical evaluation (for a configuration using flat and parallel interfaces), and in 2D by a comparison with a Finite Difference Method code (for a configuration with rough interfaces).

Full reference:

Pinson, S., J. Cordioli, "3D modelling of spherical wave reflection on layered media with rough interfaces", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 289-295, 2015

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Autonomous assessment of seabed ripple geometry from bistatic acoustic scattering data

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The seabed environment can have a large affect on the scattering pattern from a seabed target. In particular, the angle and geometric characteristics of any directional rippling in a sandy bottom can be qualitatively similar to the acoustic scattering from aspect-dependent targets, and buried targets in particular. Knowledge of the ripple field geometry and orientation in a given area is therefore important for seabed target classification using 3D bistatic scattering characteristics, including positioning of acoustic sources relative to targets. This paper describes a machine learning method to estimate these ripple field characteristics using Autonomous Underwater Vehicles (AUVs). In the scenario of interest, a fixed or ship-based source insonifies a region on the bottom and an AUV samples the resultant scattered field around that insonified patch. The vehicle acquires acoustic data using a linear hydrophone array, and calculates the scattering amplitude from the insonified patch of bottom at a variety of bistatic angles. This information is then used for ripple parameter estimation. Because real bistatic scattering data for a variety of ripple field geometries was not available, an acoustic scattering software package was used to simulate anisotropic Goff-Jordan power spectrum scattered fields for ripple fields with different anisotropy angles and geometries. Example vectors were constructed using virtual AUV sampling of the acoustic amplitudes in these simulated scattered fields. Support Vector Machine (SVM) regression was then used to train models for estimating anisotropy angle, RMS height and ripple length-to-width ratio. Independent validation and test data sets were used to select model parameters and evaluate the validity of the models. Confidence models were constructed for error in each parameter estimate. The final confidence and SVM models were then used with the LAMSS MOOS-IvP AUV simulationn environment to demonstrate real-time ripple parameter estimation. [Work supported by ONR Code 321OA]

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Influence of shells and shell debris on backscatter strength: investigation using modeling, sonar measurements and sampling on the Belgian Continental Shelf

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Acoustic interaction theory and observation highlight the strong relation between the acoustic signal responses and the physical and biological processes acting on the seafloor and in the water column. Several descriptors such as sediment texture, porosity and surface roughness are identified as the main factors affecting the acoustic reverberation and backscatter signals. Shells can influence if not dominate the scattering on the seafloor (Jackson et al., 1986; Stanic et al., 1989 and Zhang, 1996). Scattering from both inclusions and partially buried shells on the sea-floor is described by Stanton (2000), and scattering from shells as a potential mechanism explaining the scattering above 200 kHz is highlighted by Ivakin (2009). In order to improve the knowledge on this matter, several institutions with different expertise are cooperating to integrate mathematical modeling and experimental results to better quantify the influence of shells and shell debris on the acoustic signal and scattering of sonar images. Mathematical 3D models of shell objects in a sediment matrix will be used to simulate the influence of the shells on acoustic signal and scattering. The physical arrangements of shells and their spatio-temporal population trends are also considered in the modeling. The models will be supported by direct sonar measurements of seafloor areas on the Belgian Continental Shelf, combined with sampling, visual observations, classification and shape analysis of the shells and shell debris.

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Multibeam echosounder calibration for backscatter measurements on seafloor surveys: definition of natural reference areas

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The increasing importance of seabed backscatter in seafloor-mapping raises the issue of calibration of instruments - mainly multibeam echosounders (MBES). While direct calibration techniques have been tried in this respect, inspired by fisheries acoustics or underwater acoustic metrology, the interest of *in-situ* calibration over natural reference areas presents a number of appealing advantages – among which an obvious operational efficiency and the interest of an overall intensity calibration over a target similar to the ones met under operation conditions. This technique is commonly used by space-borne radars mapping the Earth's surface from satellites.
The design of natural reference areas dedicated to backscatter measurement calibration implies a number of conditions. The topography must be flat and regular (to avoid slope-dependence) and the seabed characteristics must be as stable as possible (both in space and time). The backscatter data are expected to show a simple and smooth behaviour with angle, avoiding particular phenomena such as specular reflection or azimuth dependence (linked to polarized interface roughness). Moreover reference areas must be of dimensions compatible with the typical coverage of MBES, have to be easily accessible by survey ships, and should ideally overlap with areas already defined for bathymetry measurement calibration. Finally the local backscatter level must be accurately measured from reference calibrated sensors, and stability monitoring of the seabed characteristics must be conducted.
Several projects have already been initiated for defining such areas, in France, Belgium and UK. All are defined in shallow-water areas close to harbour facilities. A common cruise over the three areas is to be conducted (June 2015) by *RV Belgica*. After discussing the issue of *in-situ* calibration of MBES and the characteristics required for reference areas, the paper presents the three areas together with measurement and ground-truthing results; and a practical example of applying this reference area concept to the calibration of a MBES on a survey launch.

Full reference:

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A swath Doppler system for measuring bedload movement

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We report on the development of a new instrument for measuring bedload velocities remotely along a O(1 m) wide swath. The system is designed with transducer geometries that are used in multi-beam sonar but extended by incorporating Doppler sonar signal processing. We report on results from a numerical model used to identify the limitations and capabilities of the approach, and also present preliminary results from an experiment carried out at the Saint Anthony Falls Laboratory (Minneapolis, USA). The model simulates sonar operation incorporating acoustic beam patterns, idealised flow structures and a representation of bottom backscatter and transport (bedload). The system - both modelled and realized -- operates at 500 kHz centre frequency. The software-defined radio data acquisition and control system limits us at present to 8 independent receiver channels, and consequently the along-swath resolution that can be obtained with the present realization of the system is only O(10 cm). The laboratory experiment was carried out in active sediment transport conditions using 400 um median diameter sand and up to 1 m/s unidirectional flow velocities. The results presented focus mainly on the bed material velocity at the sediment-water interface, but the possibilities for obtaining the 2-d velocity field above the bottom are also explored.

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Modelling Doppler sonar measurement of bedload transport: what exactly are we looking at?

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Measurement of bedload transport in a field setting is challenging. Direct measurements can be made using pressure-difference traps or pits requiring user interaction or which typically provide time integrated measurements. Acoustic methods for sampling in bottom boundary layer environments have significant advantages being non-invasive and robust. There have been several indications that Doppler sonar returns from the bottom contain information on bedload transport both from field observations (Rennie and Villard, 2004; Rennie and Millar, 2007) and laboratory trials (Traykovski ,1998; Stark et al. 2014). The near bottom acoustic return in Doppler sonar is highly complicated by the occurrence of sidelobe returns and strong backscatter gradients. We explore the potential of Doppler sonar for bedload transport measurement through the use of a Doppler acoustic backscatter model. Our overall modelling goal is to develop a better understanding of the near bottom acoustic signal, to quantify the accuracy and reliability of acoustic bedload measurements and to optimize the sampling parameters. Preliminary model results show a signal proportional to bedload transport but absolute measurements may be elusive and will likely need to be calibrated against a reference measurement for any given field site.

Full reference:

Zedel, L. D. Barclay, A.E. Hay, "Modelling Doppler sonar measurement of bedload transport: What exactly are we looking at?", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 319-326, 2015

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Passive acoustic measurement of bedload discharge features on a sandy seafloor.

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Bedload transport monitoring at sea still remains a challenge for sedimentologists and coastal engineers. Although such measurements are required to validate sediment transport model, data and instrumental techniques that establish a detailed link between boundary layer turbulence and sediment mixture dynamics are scarce. Passive acoustic method, based on hydrophones measuring self-generated noise due to interparticle
collisions, has been mostly developed in laboratories on coarse particles during the past decades. It has been shown that the amplitude and the frequencies spectrum of the monitored signals are linked to bedload fluxes and grain size distribution. This technique shows numerous advantages: it is not disruptive to the flow field, easy to handle and cost effective. Two experiments at sea are reported here: the first one were conducted on a well sorted sandy beach opened to the swell in South Brittany and the second one by 60 meters depth in the Iroise sea on a sandy dune subjects to high tidal currents. Hydrodynamic parameters in the nearbed have been provided by Doppler velocimeters. The two sites present different acoustic landscapes. Then, signal processing has been adapted to distinguish the useful information, bedload self-generated noise, from other sound sources. At both deployments, passive acoustic data proved to fit well with the intensity of bedload transport. Since the measured signal generated by particle collisions has been discriminated confidently, an empirical model is proposed to generate a simulated signal as a summation of individual shock signals. The latter is mainly affected by moving particle size. Thus, by minimizing the error between acoustic intensity simulated and measured, the optimized granulometry can be calculated. The validity of this inversion process depends on the empirical model precision. Data acquire in a well-controlled environment are now needed to better take into account the different processes involved to generate the simulated signal.

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Acoustic measurement of mobile layer velocity and thickness in avalanching sub-aqueous granular flow

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Simultaneous measurements of flow and sediment transport represent a major challenge in aqueous environments. Significant advances have been made in the development of acoustic remote sensing instrumentation for measuring the vertical structure of nearbed flow and sediment flux without disturbing either the flow or the bed. These developments have included broadband MHz frequency acoustic systems capable of simultaneous measurements of backscatter amplitude and phase across the O(1 MHz) system bandwidth at mm-scale range resolution. Our overall research objective is to extend acoustic measurements to allow an acoustic estimation of bedload parameters. As an analogue for bedload transport, we investigate sub-aqueous granular flow on a sloping bed at the angle of repose using broadband acoustics. Results are presented from a series of granular flow experiments in a rotating drum apparatus (50 cm diameter) submerged in a larger tank of water. The sediments studied include both sand and glass beads. The median grain diameter of the sand is 0.25 mm; the glass bead median diameters range from 0.25 mm to 1.1 mm. By rotating the drum either continuously or to a fixed tilt position at the angle of repose, a thin layer of avalanching sediment is produced. The thickness and velocity of the avalanching layer are measured with a wide bandwidth coherent Doppler profiler. These acoustic estimates are compared to simultaneous “ground truth” estimates made with a video imaging system.

Full reference:

Hare, J., A.E. Hay, L. Zedel, “Acoustic measurement of mobile layer thickness and velocity in avalanching sub-aqueous granular flow”, Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 335-342, 2015

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Measuring multi-phase flow with a multi-frequency acoustic profiler

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Multi-frequency coherent Doppler profilers have been developed recently for near-seabed measurements of velocity and backscatter amplitude, in principle enabling simultaneous and co-located estimates of the size, concentration, velocity and flux of suspended sediments. Estimating particle size and concentration along the profile, however, requires inversion of the backscatter amplitudes while accounting for the alongbeam attenuation at the different frequencies by the material in suspension. This inversion is typically accomplished via a suitable model for incoherent scattering. For multi-phase (e.g., bimodal) suspensions, the model can also be extended to account for the individual concentrations and velocities of different particle classes. The present work studies an extreme case: a mixture of glass beads and polystyrene beads with known size and form factor, settling through water. Laboratory measurements are used to assess the feasibility of using inversion to extract the concentration and velocity of each particle type. Potential applications of this technique include separation of sediment velocity vs. fluid velocity (via doping with passive tracer particles), and characterizing multi-phase flows in general.

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Detection and description of sand dunes using a geomorphometric approach

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In the last decades, sandbanks and sand dunes of various shapes and sizes have been found and described on continental shelves all over the world. These structures tend to migrate and our understanding of the mechanisms regulating their dynamics is limited. These sandbanks became a concern due to the fact that they interfere with the human activities at sea. Consequently, their presence has economical and environmental impacts. The purpose of this study is to automatically detect these dunes in DTMs (Digital Terrain Models) generated from MBES data. So far, automatic techniques aiming at describing marine dune fields have always brought information such as the height, dune spacing or the orientation at local scale but never went down to a dune scale. Currently, the dunes are still manually digitized and then form parameters are calculated. This task is tedious and time-consuming. In addition, the amount of data to process being always bigger, it gets difficult for operators to keep the pace. To address this issue, we propose a geomorphometric approach. Attributes such as the slope or curvatures are estimated from DTMs. A combined analysis of the metrics maps enables to extract dunes from their environment. The following step is the determination of parameters characterizing the shape and size for each dune. This work provides knowledge about dune fields at a detailed level. Thus, the composition, spatial distribution and other aspects of sand banks can be obtained. Further research can be conducted in order to learn more about the dynamics of dune fields at an individual level.

Full reference:

Ogor, J. N. Debese, B. Zerr, T. Garlan; "Detection and description of sand dunes using a geomorphometric approach", Proc. Institute of Acoustics, vol. 37, pt. 1, pp. 349-356, 2015

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